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A dynamic simulation-based methodology for systematic assessment of floating wind workability

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Motivation

Is maintenance work influenced by platform motions?

Floating wind turbines are expected to experience **higher motions** than conventional bottom fixed turbines.
Goal of the present work is to investigate the **effect** of these low-frequency, whole-body-vibrations **on humans** and the ability to perform maintenance work.
By **quantifying workability** for a wind farm site, the introduced methodology helps to reduce uncertainties during the **O&M phase** and can be applied for commercial decision making to **improve asset availability**.

Methodology

Weather Data → Response Simulation → Workability Assessment → Quantification

Weather Data
- **Met-ocean hindcast data** of a windfarm in northern Scotland is analyzed and clustered into sea states, for each significant wave height, peak wave period and wave heading combination.
- **Occurrence probability** of each sea state is determined
- The 3000 most probable sea states are simulated

Response Simulation
- Software **RAFT v1.0.0**, developed by NREL is used to estimate the linearized system response to waves in the **frequency domain**:

$$(\boldsymbol{M}+\boldsymbol{A}(\omega))\ddot{\vec{\xi}}+\boldsymbol{B}(\omega)\dot{\vec{\xi}}+\boldsymbol{C}\vec{\xi}=\vec{F}e^{-i\omega_e t}$$

- Holistic, all rigid model includes UMaine **VolturnUS-S** reference platform, IEA 15 MW turbine and catenary mooring lines

Workability Assessment
- Simulated **spectral response** is used to estimate **workability** in the **nacelle** and on the **platform** for each sea state.
- **3 Workability Indicators** with individual limits and procedures:
  Nordforsk Seakeeping Criteria
  ISO 2631-1 (comfort)
  ISO 6897

Quantification
- Based on each sea state's occurrence probability a site-specific **workability decrease** is summed up for all non-workable simulation results.
- 2 Approaches are introduced: **threshold exceedance** and **relative exceedance**.

Workability Indicators

Nordforsk
- Defines limits for save sea keeping conditions on vessels
- Previously used in floating wind & vessel specific projects
- *Transit Passenger* threshold is the 'most applicable for floating wind'

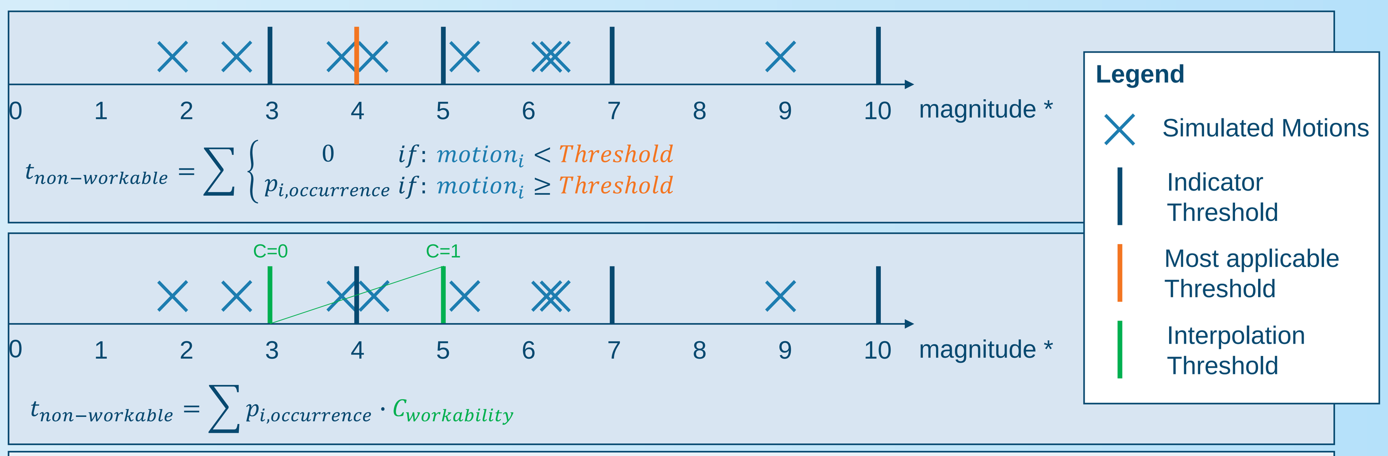
ISO 2631-1
- Defines mean acceleration values for human comfort
- Applies weights to account for human perception at different frequencies
- *A little uncomfortable* threshold is the 'most applicable for floating wind'

ISO 6897
- Defines satisfactory acceleration values for buildings and structures
- Limit values are given for a range of frequencies to account for human perception
- *Buildings with general purpose* threshold is the 'most applicable for floating wind'

Quantification approaches

Threshold exceedance
- Sums occurrence probability of all simulations that breach the 'most applicable threshold for floating wind'
- Disadvantage: reduces human comfort to a binary problem

Relative exceedance
- Multiplies occurrence probability with interpolated factor before summing.
- Both thresholds next to the 'most applicable threshold for floating wind' are used



Schematic view of a fictional * workability indicator and its **thresholds** on a scale. Discretely simulated motions are indicated by **X**, representing exemplary results, each one being one sea state.

Upper figure shows threshold exceedance approach, classifying motions on the left of orange threshold to be **workable**, motions on the right to be **non-workable**. Summing the occurrence probability $p_{i,occurrence}$ of all non-workable sea states gives the non-workable time $t_{non-workable}$.

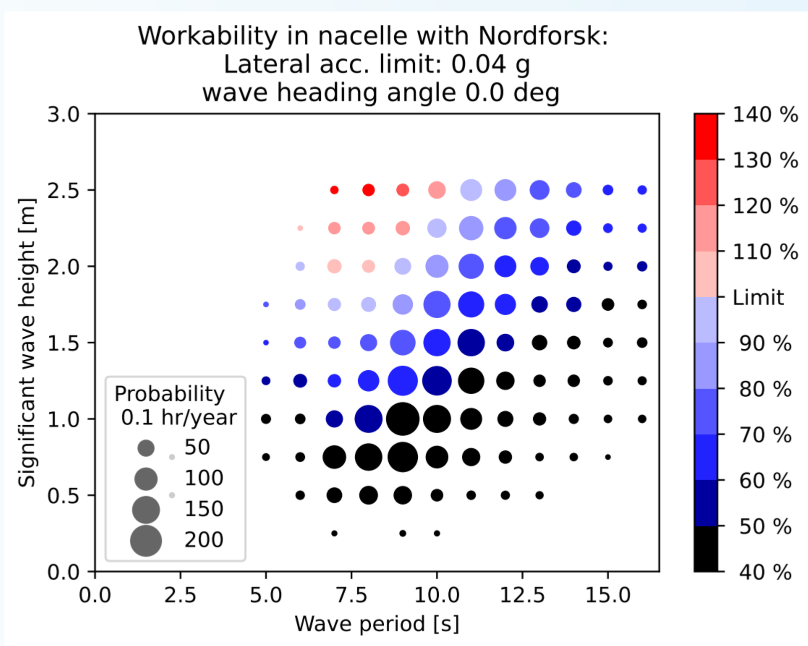
Lower figure shows relative exceedance approach, where motions between the interpolation thresholds will contribute to the **non-workable** time relative to their position-based **interpolation factor** $C_{workability}$ (depicted are examples with $C = 0{,}4$ and $C = 0{,}6$).

** Different indicators define different thresholds in terms of **values** (e.g., magnitude and frequency dependency) and **scale** (e.g., root mean square acceleration, roll displacement, weight factors), which is why a fictional example is shown and no direct comparison between indicators is possible.*

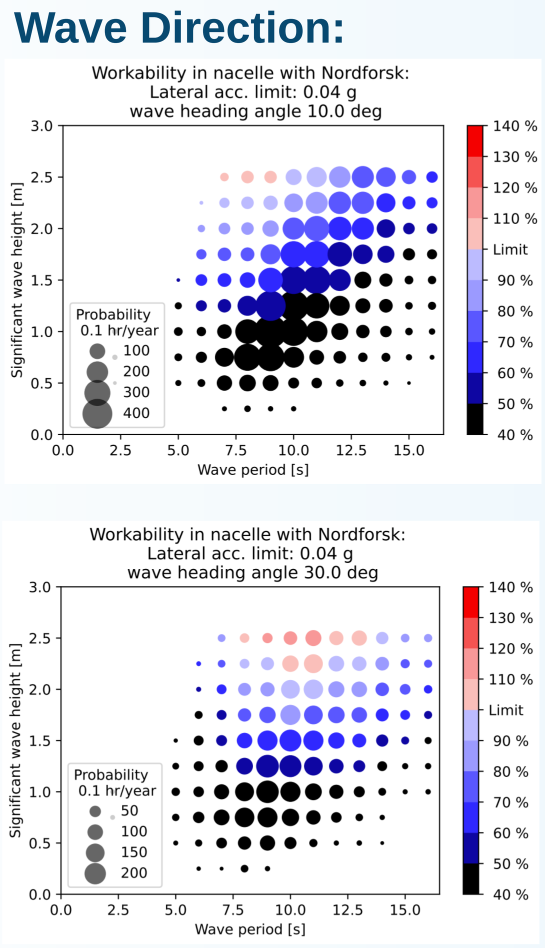
Results

Workability per sea state

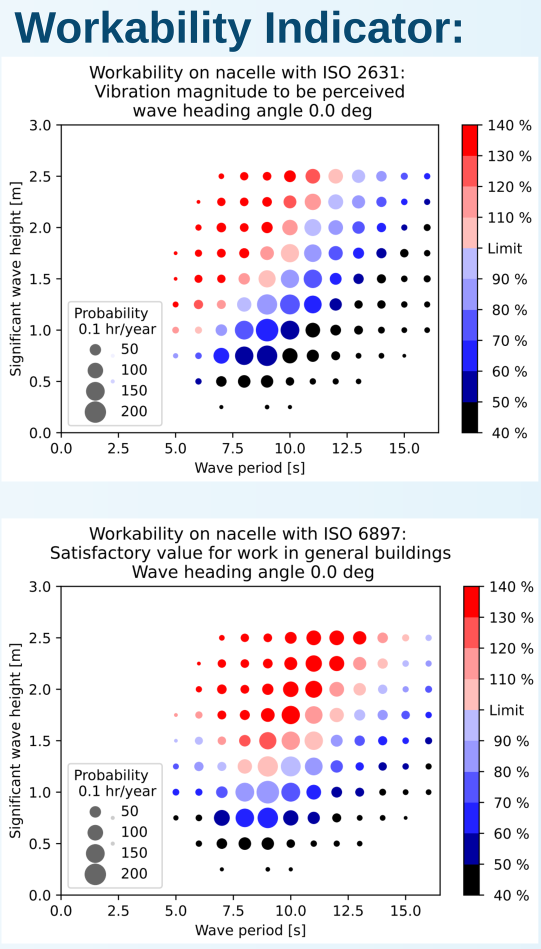
Below plots show workability for specific sea state (Hs, Tp and wave heading). Color indicates breach of workability limits (in percent)



Wave Direction:

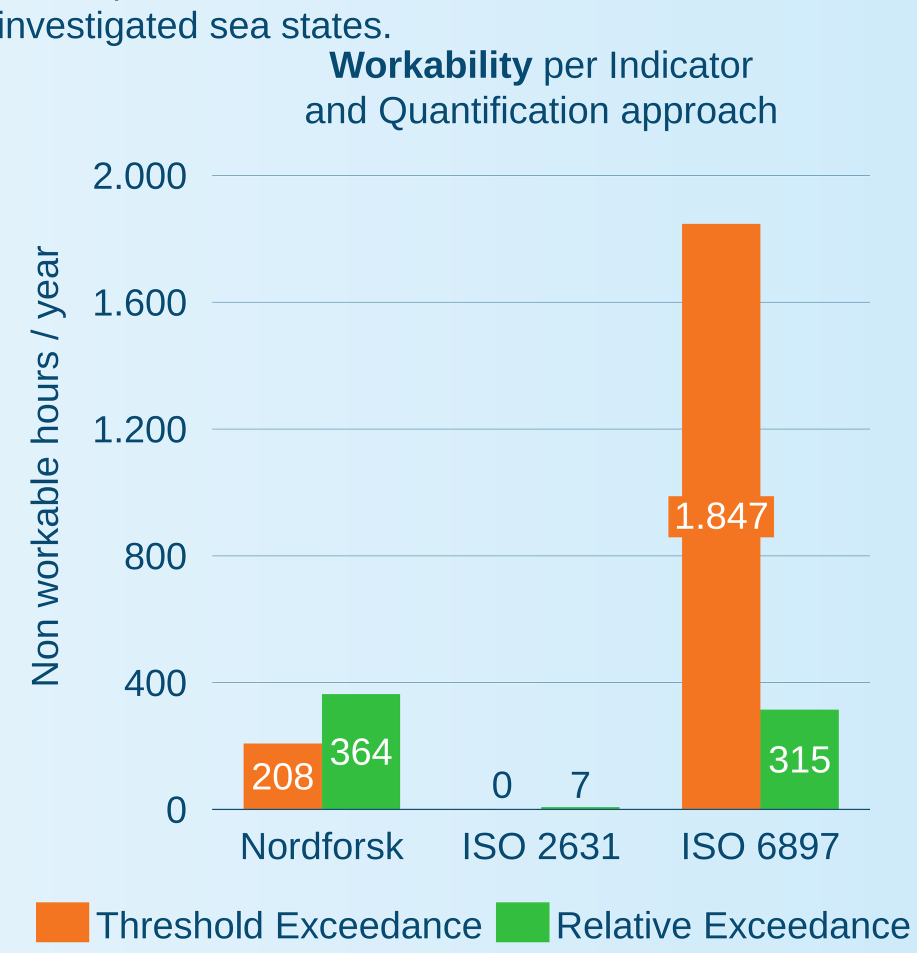


Workability Indicator:



Workability quantification for Scottish site

All observed breaches of the workability limits are due to **horizontal acceleration in the nacelle**. Motion in vertical and rotational direction, as well as all motions perceived on the platform level are considered **workable** for all investigated sea states.



The results vary significantly between the workability indicators due to their specific area of applicability, which is traditionally not floating wind.
The most applicable indicator is **Nordforsk,** which estimates non-workable conditions of:
208 hr/yr for threshold exceedance
364 hr/yr for relative exceedance

The Nordforsk value for relative exceedance is in the same order of magnitude as for ISO 6897, which enables **good comparison** between **two different indicators** for the investigated site and floating WTG.

Conclusions

Expected turbine motions may interfere with human comfort during maintenance work
→ Workability is likely to be reduced for the investigated site and floating WTG

Non-workable conditions vary with
- Indicator type
- Significant wave height
- Peak wave period
- Wave direction

→ Holistic & site-specific analysis is necessary to investigate workability sufficiently accurately

Significant discrepancies are found between different workability indicators and thresholds
→ The floating offshore industry needs a standardized indicator and methodology to estimate workability

Workability limits are expected to change for various types of work e.g., inspection, troubleshooting, craning, major component replacement
→ Need for more detailed analysis, thresholds and crosscheck with real life data

Inclusion of a site-specific workability assessment is recommended during the Integrated Load Analysis (ILA) of any floating wind farm development
→ Reduce uncertainties with potentially negative influence OPEX and business case